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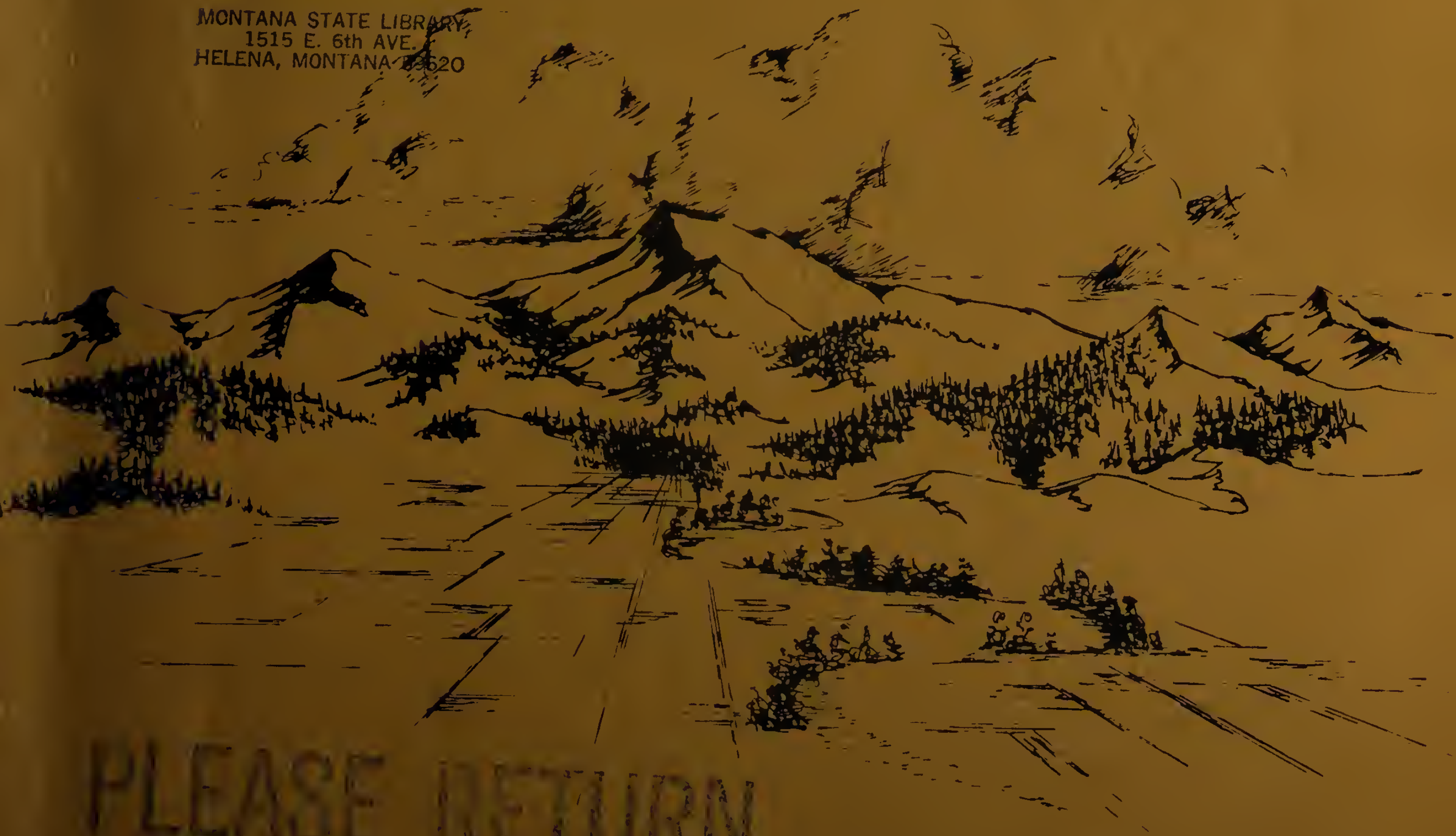

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GEOLOGY AND PLANNING IN
LEWIS AND CLARK COUNTY,
MONTANA

by

Gloria Pao

Submitted to
City-County Planning Department
Don Kinney, Director
September 1973

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The Resources Development Internship Program
has been financed during 1973 by grants
from the
Economic Development Administration,
Jessie Smith Noyes Foundation,
National Endowment for the Humanities,
National Science Foundation
and by more than one hundred community
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ABSTRACT

"Until geologic information is integrated in its proper perspective with other factors of the physical, social, and economic environment, planners and other non-geologists may continue to use geologic information and professional services of the engineering geologist only occasionally, and then only...after a geologic problem has caused loss of property or even of life." (Gardner and Johnson, 1971, in Environmental Planning and Geology.)

The first part of this report looks at the relationship between geologic data and planning in general and as seen by some people involved with cases outside of Lewis and Clark County. This is included for the interest of the City-County Planning Department which is at the starting stage of incorporating geologic information into its planning process.

Lewis and Clark County is dealt with in the second portion of this report. While the Planning Department does recognize the significance of applying geologic data to planning (particularly land use planning), much of the necessary geologic information is lacking. In spite of this, the Planning Department has gathered what data is available and is producing general physiographic and slope maps. Eventually, it aims to develop matrices for guidance in planning. Hopefully, with the arrival of two geologists in the summer of 1974, more geologic data can be obtained which will prove useful in planning. Some engineering geology tables and notes which may be helpful to the Planning Department are included in the appendix. The maps mentioned in this report that deal with the project area are located in the Planning Department office.

ACKNOWLEDGEMENTS

Sincerest thanks go to the following people who so willingly contributed their knowledge and time: Don Coffin, Arnold Boettcher, Kathy Wilke of the U.S. Geological Survey; Chuck Harnish, Wayne Phillips, Jim Whipple of the U.S.D.A. Forest Service; Roland Johnson, Ken Bolland, Art Olson of the U.S.D.A. Soil Conservation Service; Tom Dundas of the Montana State Department of Intergovernmental Relations; Bill Michno of Foundations and Materials Consultants, Inc.; the Helena Public Library staff; and I am especially grateful to Don Kinney, Dan Obermeyer, Dennis McCahon, Pete Lenmark, Clark Pinkerton, Pat Bates, Bob Bennett, and Ray Riccardi of the City-County Planning Department for their professional assistance and unprofessional moral support.

INTRODUCTION

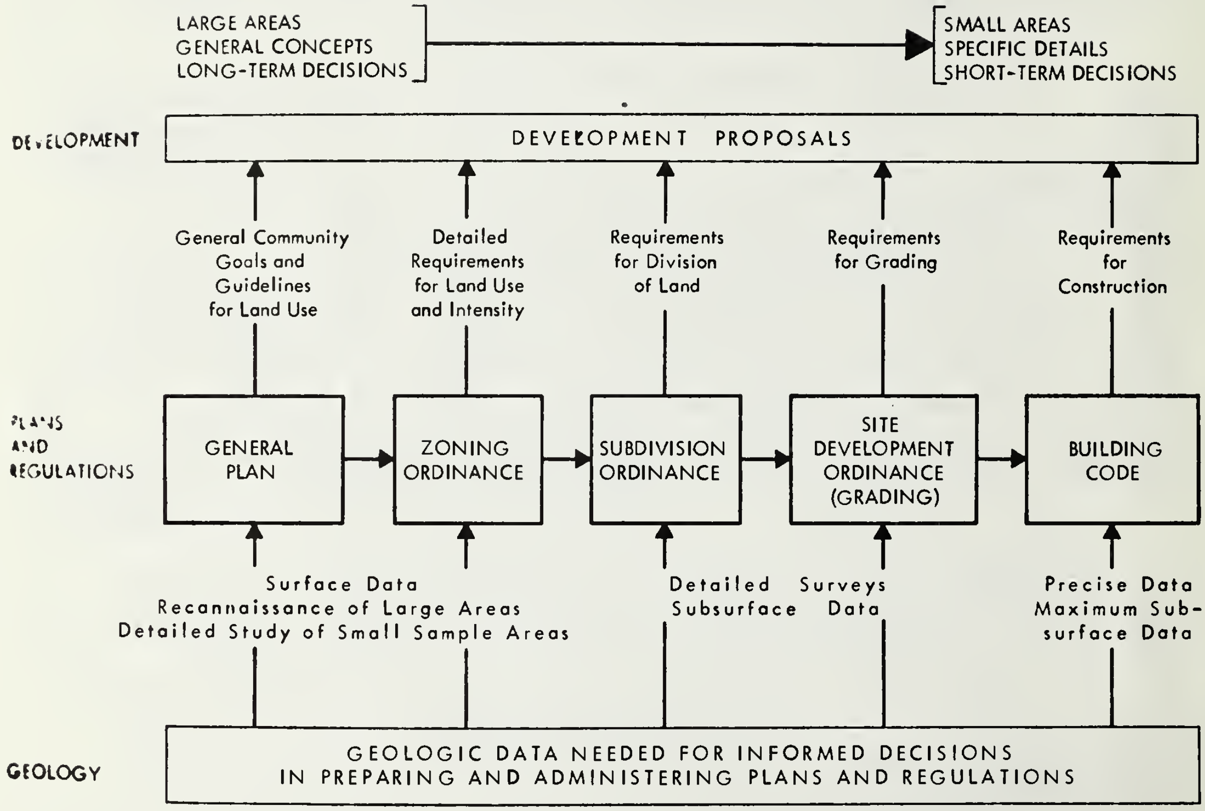
Geology in Planning

"Planning is an intellectual process wherein 1) data are analyzed and 2) a program is formulated to bring about a desired result. It is a process by which change is initiated, promoted, and controlled in an orderly manner or, more realistically in today's context, by which some degree of order is brought to inevitable change" states Peter T. Flawn, author of Environmental Geology: Conservation, Land-use Planning, and Resource Management. He adds that land-use planning that does not consider geologic data has diminished chances of success since not all of the pertinent data have been analyzed.

Geology is defined as "the science which treats the earth, the rocks of which it is composed, and the changes which it has undergone or is undergoing" in the Dictionary of Geological Terms (American Geological Institute, 1962). Some problems of urban land use that are related to geology occur as natural geologic hazards (such as earthquakes and landslides); other problems, such as groundwater pollution and instability of cuts, pose existing or potential threats due to poorly planned activities of man; other problems may have more to do with the economics of land use or development than with safety (for example, difficulty of excavation); and there may be problems that concern aesthetics (for instance, the destruction of some aesthetic features of the landscape by unwise development).

Planning for the most efficient adjustment of man's use of the land to the physical features and characteristics at and below the earth's surface can result from collecting data provided by geologic and topographic maps, by predictions of landslides and other geologic hazards, by engineering geology and soil mechanics investigations, and by an inventory of available mineral resources and water supplies.

The diagram on the following page was presented in "An Experiment in Using Geology for City Planning- The Experience of the Small Community of Portola Valley, California" by Mader and Crowder (1971) and it shows the relationship between geology and the planning-regulation-development process.


LARGE AREAS
GENERAL CONCEPTS
LONG-TERM DECISIONS
SMALL AREAS
SPECIFIC DETAILS
SHORT-TERM DECISIONS
DEVELOPMENT
DEVELOPMENT PROPOSALS
General Community Goals and Guidelines for Land Use
Detailed Requirements for Land Use and Intensity
Requirements for Division of Land
Requirements for Grading
Requirements for Construction
PLANS AND REGULATIONS
GENERAL PLAN
ZONING ORDINANCE
SUBDIVISION ORDINANCE
SITE DEVELOPMENT ORDINANCE (GRADING)
BUILDING CODE
Surface Data
Reconnaissance of Large Areas
Detailed Study of Small Sample Areas
Detailed Surveys
Subsurface Data
Precise Data
Maximum Subsurface Data
GEOLOGY
GEOLOGIC DATA NEEDED FOR INFORMED DECISIONS IN PREPARING AND ADMINISTERING PLANS AND REGULATIONS

Geologic Data Needed

Collection of the following geologic data may provide useful information for planning purposes:

- Topographic map
- Geologic map
- Surficial geology map
- Physiographic map
- Soils map
- Depth to bedrock
- Thickness and structure of rock and soil layers
- Strength characteristics of rocks and soils (shear strength, bearing capacity, etc.)
- Corrosivity of geologic formations and soils
- Extent of weathering of rocks and soils
- Effect of frost action
- Potential landslide and soil creep
- Fault movement, earthquakes, and other dynamic characteristics
- Physical limitations and costs
- Ease of excavation
- Mineral resources (metallic and non-metallic)
- Slope characteristics (degree, aspect)
- Surface and groundwater information:
  - Groundwater potential
  - Groundwater chemistry
  - Acquifer stirage and transmission characteristics
  - Thickness and distribution of acquifer units
  - Permeability and porosity of rocks and soils
  - Static water level
  - Depth to water table
  - Groundwater recharge potential
  - Distribution and types of potential sources of pollution (septic tanks, sanitary landfills, etc.)
  - Flood hazard

Methodologies of Other Projects

In A Geologist Views the Environment, John C. Frye describes a project to characterize the physical environment that includes:

- Analysis of the physical character of the major landforms within the county
- Interpretation of the relation between geologic units near the surface and the agricultural soil units
- Establishment of the character of the layers of rocks and glacial deposits penetrated by drilling
- Definition of the occurrence and character of the water-bearing strata in the glacial deposits and deeper bedrock layers
- Determination of the feasibility of water-resource management programs
- Determination of the feasibility of waste management programs
- Delineation of the geographic occurrence and description of the characteristics of construction material resources
- Location of commercial mineral resources and assessment of their economic value
- Determination of the engineering characteristics of the geologic units near the surface
- Geologic evaluation of surface reservoir conditions and proposed reservoir sites.

This type of data is based on both field work by surficial geologists, engineering geologists, groundwater geologists, stratigraphers, and economic geologists, and laboratory work. The laboratory work includes studying cores and cuttings of deposits; making chemical, textural, and mineralogical analyses of all deposits and rocks; determining physical properties; making economic analyses of the mineral resource situations; and studying the occurrence, quality, availability, development, and replenishment of groundwater. The results of these studies are compiled on interpretive maps which the planning department combines with the results of studies by other agencies and by the department itself for preparation of maps that show recommendations for land use. Finally, these maps along with nontechnical text serve as a basis for long-range development planning.

Hackett and McComas (1969) describe the method for interpretation of geologic data in Geology and Planning in McHenry County in four steps:

1) Detailed surficial mapping and subsurface study, supported by laboratory analysis, to differentiate all geologic units primarily on the basis of composition and physical properties.
2) Evaluation of geologic units in terms of their mineral resources and their engineering and hydrologic properties.
3) Preparation of interpretive maps in which areas are graded for specific land uses.
4) Analysis of terrains in which land units are differentiated on the basis of physiography and earth materials and evaluated in terms of their suitability for various land uses.

Types of maps used for engineering geology are outlined by Matula (1971) in "Engineering Geologic Mapping and Evaluation in Urban Planning" as follows:

—Types of maps used for engineering geology

Map type Scale	Synoptic maps 1:100,000-1:200,000	Basic maps 1:25,000-1:50,000	Detailed maps 1:5,000-1:10,000
Map use	Regional planning 1. Land use 2. Conservation 3. Highways 4. Water management	Local planning 1. Preliminary site evaluation 2. Geologic hazards 3. Construction materials sources	Design and development 1. Residential 2. Commercial 3. Industrial 4. Roadways and utilities 5. Environment rehabilitation
Amount of detail Rock units	Groups, formations	Formations, lithologic types	Lithologic types, engineering geologic types
Hydrology	Symbols showing depth and character of ground water	Hydroisobaths, symbols showing corrosiveness	Hydroisohypses in graduations of 1 m
Geodynamic processes	General areas shown by point-symbols	Boundaries shown, evaluation of activity	Detailed mapping and "hazards" evaluation
In delimiting areal units	Areas—zones (similar morphology & foundation materials)	Zones—subzones (uniform composition of foundation soils)	Districts (uniform foundation conditions)
Documentation points per km²	1–2	8–14	40–50

In "Engineering Geologic Maps for Regional Planning" Gardner and Johnson (1971) give these tabular headings to accompany their maps:

1.—*Tabular text headings, to accompany the engineering geologic maps*

(1) Engineering geologic map unit, with map symbol	(2) Equivalent geologic map unit (s)	(3) Description, structure, and thickness	(4) Topographic expression, and surface relief	(5) Weathering, and ancient soil profiles
		(see Table 2 for outline of contents)		

DESCRIPTIVE INFORMATION

(6) Workability	(7) Surface drainage, and erosion	(8) Ground water	(9) Suitability for waste disposal
Excavation: Equipment type, or method Compaction: Characteristics Equipment type Drilling	Runoff rate Erosion susceptibility	Permeability Water table: Depth Character Yield to wells Quality Use	Soil absorption, Septic tanks Sanitary-landfill sites

(10) Foundation stability	(11) Slope stability	(12) Probable earthquake stability	(13) Use
Expansive clay Collapsible (loessial) silt Subsidence	Possible failure types Hazardous situations Trench-wall stability	Most hazardous potential	Building or construction material Common land use

INTERPRETIVE INFORMATION (with topics included)

—*Outline of topics included in column 3 of the tabular text: "Description, Structure, and Thickness"*

Dominant lithology and texture
Minor lithologies and textures
Grain size
Grading or sorting
Grain arrangement
Significant mineral composition
Consolidation by overburden
Relative density
Consistence

Stratification
  Character
  Continuity
  Problem strata

Color
Potential volume change (for clayey materials)

Structure
  Attitude
  Bedding
  Foliation
  Joints
Thickness

THE PROJECT

Introduction to Lewis and Clark County, Montana

The Helena Lewis and Clark City-County Planning Board (established July 1, 1973) has jurisdiction for the comprehensive planning process and implementation within Lewis and Clark County and the City of Helena. They function under planning enabling legislation of the State of Montana and are responsible for developing master plans and elements such as housing, transportation, and land use, and for implementing them. The Planning Board has the responibility of reviewing and making only recommendations to the elected public officials of the City or County. Only these elected officials have the power to make decisions regarding plan acceptance and implementation.

There are three major types of landowners in Lewis and Clark County: 48% (1,679 square miles of mainly national forest land) is federally owned; 47% (1,644 square miles) is privately owned; and less than 5% is state owned.

Land use is reflected by the general physical characteristics of the area. The mountainous region to the west and north of the county lends itself to forest products and recreation while foothills sections are good for range land and help to make beef cattle the major source of agricultural income. The irrigated land along the east and northeast border of the county is used mainly for the production of hay and small grains.

The population of the county was approximately 34,000 in 1970 and is expected to increase to 38,000 by 1980. The population of the county is clustered in the southern and eastern portions with Helena being the largest city. It had a population of approximately 22,700 in 1970 and is growing rapidly. This has lead to an increase in subdivision developments in the Helena Valley and surrounding mountainous areas and, due to the immense scenic appeal (Especially around lakes), construction is also fluorishing in more "remote" parts of the county. As a result, the Planning Board has become aware of several problems relating to geology such as: damage due to building upon flood plains; decreasing availability of groundwater; contamination of groundwater (from septic systems, etc.); damage as a result of building upon (potentially) unstable slopes; costs of providing public service to outlying areas; and aesthetic impact of man's activities. Therefore, the Planning Board has become concerned with obtaining geologic data upon which it can base wise planning decisions.

Geology of Lewis and Clark County

Lewis and Clark County is located in the west central part of Montana. It covers 3,513 square miles of which 36 square miles represent water surface area (water areas are mostly confined to the east and southern portions of the county). Over 70% of the land in the county is mountainous with the remainder in foothills or intermountain basins. Elevations vary from 9,419 foot Red Mountain in the west central part of the county to elevations of approximately 3,600 feet in the east central portions where the Missouri River leaves the county. A wide range of geologic features are covered, including the Continental Divide in the west, plains, intermontane valleys (ex., Helena Valley), cirques and moraines from mountain glaciation, folded and faulted rocks (mainly showing a northwesterly trend), gorges (ex., Gates of the Mountains), intrusive igneous masses (ex., Boulder Batholith), lakes (ex., Canyon Ferry Lake), and more.

The geological history of the county includes sedimentation, regional uplift, structural deformation, and erosion. During the Precambrian era thousands of feet of sediments were deposited forming a thick sequence of sedimentary rocks. Sedimentation continued during the Paleozoic era interrupted by brief periods of uplift and erosion. In early Tertiary time widespread regional uplift, faulting, erosion, and deformation occurred in mountainous parts of the county resulting in the removal Paleozoic and Mesozoic sediments from large parts of the county. Granitic rocks intruded and volcanic rocks covered parts of the county. There was addition deformation, uplifting, and erosion in later Tertiary time leading to dissection of the mountains and development of mountain valleys. Glaciation occurred during the Pleistocene epoch in the mountainous areas and resulted in the formation of moraines and outwash deposits. A more detailed description of the geologic history of the greater Helena mining region by Pardee and Schrader (1933) is given on the next page.

The geologic history of the region includes two contrasting periods, the earlier of which was characterized by the accumulation of marine sediments that range in age from Algonkian to Upper Cretaceous. The later period was one of mountain building and erosion, and its chief events are listed below.

1.	Folding and elevation	Late Cretaceous or early Eocene.
2.	Overthrust faulting	Early Eocene.
3.	Extrusion of andesitic lavas south of Helena	Early Eocene.
4.	Intrusion of Boulder batholith	Early Eocene.
5.	Period of general crustal stability and reduction of the region by erosion to a surface of low relief	Middle Eocene to early Oligocene.
6.	Intrusion of Marysville and Gould stocks and probably other granitic outliers	Early or middle Oligocene.
7.	Extrusion of andesitic lavas, Stemple to Wolf Creek	Middle Oligocene.
8.	Gentle warping and faulting that produced shallow depressions areally coextensive with present intermontane valleys. Showers of volcanic ash occurred during the same period	Middle Oligocene.
9.	Erosion interval. Shown in Townsend Valley.	
10.	Uplift of the present mountains and continued depression of the intermontane basins and at the same time an uplift of the general region. Extrusion of rhyolite, dacite, and basalt	Miocene or Pliocene.
11.	Dissection of the mountains. Development of the mountain valleys and the terraces	Pliocene and Pleistocene.
12.	Local glaciation in the higher mountains and lowland glaciation in the extreme northern part of the region	Middle and late Pleistocene.

The late Cretaceous and older sedimentary rocks are all involved in a series of northwestward-trending folds. Along the east side of the region overthrust faults related to the great Lewis overthrust of Glacier National Park cause Belt rocks to overlie rocks of Paleozoic and Mesozoic age. (See pl. 2.) Large normal faults occur near Marysville, and faults of moderate displacement near Helena. The Tertiary beds are slightly deformed by folds and faults that are unrelated to the structure of the older rocks.

Geologic Data Available and Methodology

The City-County Planning Department which advises the Planning Board is largely dependent upon specialists of other agencies to provide geologic data such as those listed on page 4 of this report. So far, however, these agencies have been short of funds and manpower. Fortunately, the county is not overwhelmed by serious problems from a geologic point of view; yet, this may also be looked upon as a drawback since it tends to eliminate the area from priority attention for studies. The data that is available to the Planning Department, though, includes the following:

- Geologic map of Montana
- Geologic map of the Northern part of the Boulder Batholith and adjacent area, Montana (Knopf, 1963)
- Geologic map of the greater Helena mining district (Pardee and Schrader, 1933)
- Map showing area of Boulder Batholith and traces of overthrust faults (Pardee and Schrader, 1933)
- Topographic maps
- Arial photographs
- ERTS photograph
- Map of physiography and glacial geology of western Montana (Alden,1953)
- Table of geologic formations in Montana (Perry, 1962)-see Appendix A-1
- Table of water-bearing properties of sedimentary rocks of the Helena Valley (Lorenz, 1951)-see Appendix A-2
- References related to the area-see Bibliography
- Soils data (U.S.D.A., Soil Conservation Service)

Despite the lack of much needed geologic information, the Planning Department has attempted to gather and consolidate as much as possible and is currently forming a slope map and a physiographic map.

The physiographic map depicts areas of stream deposition and erosion and areas of glacial deposition and erosion. These processes were separated due to the fact that stream deposits tend to be stratified and sorted while glacial deposits do not. This map also shows rock types of the county as sedimentary (S), limestone (L), sedimentary including limestone (SL), intrusive igneous (I), volcanic igneous (Iv), and alluvium (Q); this seemed the most pratical division for engineering geology purposes at the county level given the limited amount of data available (see Appendix A-3). The map is based upon the physiography and glacial geology map of Montana, the geologic map of Montana, the geologic map of the northern Boulder Batholith and adjacent area, and topographic maps.

The slope map is based upon topographic maps and the following divisions are used for engineering and cost reasons and due to the scale of the map: 0-10%, 10-20%, 20-40%, and over 40%. Information about slopes is useful in land use planning for landslide evaluation, sewage disposal system design, selection of transpotation and utility line routes, drainage and erosion control, etc..

These are general maps which can be used as a starting base for information to be used in elements of area plans (more specific data are required for local usage). The Planning Department hopes eventually to come up with matrices for guidance, including types (of rocks) vs. characteristics, activities vs. characteristics, and activities vs. types. Examples of the activities vs. characteristics matrices developed by the State Department of Natural Resources are shown in Appendix A-4.

Even though other agencies have been unable to directly aid the Planning Department, some have produced geologic reports concerning certain areas within the county which are useful to the Planning department (for instance, Reconnaissance Geology of the Mike Horse Planning Unit, Lincoln Ranger District (Whipple, 1973, U.S.D.A. National Forest Service), and Water Resources of the Upper Blackfoot River Valley, West-Central Montana (Coffin and Wilke, 1971, U.S. Geological Survey). Also, the staff of other agencies in the area are willing to contribute what data they do have, their expertise, and their time to the greatest extent possible. Attempts are being made at collecting data so that unknowing duplication of effort by agencies is avoided and so that agencies may incorporate collection of data for planning purposes into their work when possible. Futhermore, the State Department of Intergovernmental Relations is making an effort to computerize and coordinate data from various sources.

Future Outlook

In the summer of 1974, two geologists will begin field work in Lewis and Clark County and, hopefully, more geologic information of use to planners will be obtained. It would be ideal if maps such as those presented in the U.S. Geological Survey folios could be developed for the region. These usually describe the following:

Thickness and distibution of units
Terrain, natural slope, and slope stability
Drainage, permeability, and water table
Frost susceptibility
Earthquake stability
Excavation characteristics

Suitability for subgrade, fill or borrow, and compaction characteristics
Suitability for foundations
Points of geologic interest

These characteristics are usually qualitatively described in terms of high-low or good-fair-poor. Numerical values are commonly given for size classification, density, plasticity index, etc. Interpretive maps depicting the suitability of different geologic formations for different land uses can produced from the geologic folio maps (however, individual site plans will require more intensive investigations by specialists).

Another source of manpower for obtaining geologic information might be college students. Perhaps geology students at the University of Montana in Missoula and the Montana State University in Bozeman could do studies in Lewis and Clark County which would benefit both the students and the Planning Deaprtment.

Appendix B includes engineering geology tables and notes which may be helpful to the Planning Department as it progresses toward its goal of meaningfully applying geologic data to land-use planning.

APPENDIX A-1

SEDIMENTARY ROCKS

CENOZOIC ERA	QUATERNARY		Alluvium (Recent River Deposits) Glacial Moraine		
	TERTIARY		Tertiary Sediments (Bozeman Beds)	Flaxville Gravel Fort Union Formation	(Tongue River Member (Lebo Member (Tullock Member
MESOZOIC ERA	UPPER CRETACEOUS		St. Marys Formation	Hell Creek Formation	
		Montana Group	Horsethief Sandstone	Lennep Sandstone	Fox Hills Sandstone
			Bearpaw Formation		
			Judith River Formation	Pierre Formation	
			Claggett Formation		
			Eagle Formation		
			Telegraph Creek Formation	Telegraph Creek Formation	
		Colo. Group	Marias River Formation	Niobrara and Carlile Formations Frontier Formation	
	LOWER CRETACEOUS		Blackleaf Formation	Mowry Formation Thermopolis Formation	
			Kootenai Formation	Cloverly Formation	
	JURASSIC	Ellis Group	Morrison Formation Swift Formation Rierdon Formation Sawtooth Formation	Sundance Formation (Gypsum Springs)	
	TRIASSIC		Thaynes Formation Woodside Formation Dinwoody Formation	Chugwater Formation	Spearfish Formation
PALEOZOIC ERA	PERMIAN		Phosphoria Formation	Embar Formation	Minnekahta and Opeche Formations
	PENNSYLVANIAN		Quadrant Quartzite Amsden Formation	Tensleep Sandstone	Minnelusa Formation
	MISSISSIPPIAN		Alaska Bench Formation (Tyler Formation)	(Brazer Limestone)	
		Big Snowy Group	Heath Formation Otter Formation Kibbey Formation		
		Madison Group	Madison Limestone Sappington	Charles Formation Mission Canyon Formation Lodgepole Formation (Exshaw-Bakken-Englewood)	
	DEVONIAN		Three Forks Formation (Potlatch Anhydrite Formation) Jefferson Formation Maywood Formation	Three Forks Formation Birdbear (Nisku) Formation Duperow Formation Souris River Formation Dawson Bay Formation Prairie Evaporite Formation Winnipegosis Formation (Ashern Formation)	
	SILURIAN			Interlake Formation	
	ORDOVICIAN			Stony Mountain Formation Red River Formation Winnipeg Formation Whitewood Formation	Big Horn Dolo.
	CAMBRIAN		Red Lion Formation Hasmark Formation Silver Hill Formation Flathead Formation	Grove Creek Formation Snowy-Range Formation (Dry Creek Member) Pilgrim Limestone Park Shale Meagher Limestone Wolsey Shale Flathead Sandstone	Deadwood Formation
PRECAMBRIAN		Belt Series Missoula Group	Rock Rabbit Formation Bouchard Formation Sloway Formation Lopine Formation Spruce Formation	Pilcher Quartzite Garnet Range Quartzite McNamara Formation Bonner Quartzite Miller Peak Argillite	Greenhorn Quartzite Marsh Shale Helena Limestone Empire Shale Spokane Shale
		Piegan Group	Wallace Limestone	Wallace Limestone	Greyson Shale Newland Limestone
		Ravalli Group	St. Regis Formation Revett Quartzite Burke Formation	Grinnell Argillite Apekunny Argillite	Chamberlain Shale
		Pre-Ravalli	Prichard Formation	Altyn Limestone	Neihart Quartzite
			Cherry Creek Series (Pony Series)	Stillwater Complex	

—LIST OF GEOLOGIC FORMATIONS IN MONTANA

APPENDIX A-2

.--Sedimentary rocks of the Helena Valley and their water-bearing properties

Age		Formation	Thickness (feet)	Lithologic character	Water supply
Quaternary		Alluvium		Sand and gravel deposited in broad coalescing fans along the southern and western slopes of the valley, thinning and grading into finer materials toward the central part of the valley.	**Yields adequate supplies for domestic and stock purposes except in areas where very thin and fine-grained; in some places yields are sufficient for irrigation. Water is highly mineralized in places.**
Tertiary		Auriferous gravels		Local deposits of locally derived boulders, cobbles, gravel, and sand; composed mainly of andesite, vein quartz, and granite fragments near Montana City; of quartz monzonite and limestone fragments in Last Chance Gulch.	**Yield moderate supply of water to a few wells.**
		"Lake beds"		Mainly fine-grained light-colored clay of volcanic origin interbedded with sand and gravel and some lignite; indurated tuffs present in south part of area between Helena and East Helena. Broad exposures in southeast part of valley; mantled by alluvium elsewhere.	**Lower beds in central part of valley contain water under artesian pressure and will yield large supplies to wells. Yields sufficient for domestic and stock use in areas where beds are composed of clay and interbedded sand. Indurated tuffs yield only very small quantities of water to wells.**
Cretaceous				Originally sandstone, and shale but later altered by intense metamorphism.	**Not water bearing.**
Carboniferous	Pennsylvanian	Quadrant quartzite	150-190	Quartzite, sandstone, and some interbedded white limestone; altered by contact metamorphism.	**Yields small supplies, but not important as source of water.**
	Mississippian	Madison limestone	2,600	The upper part is very massive light-colored limestone that has been altered to white marble in the vicinity of Helena. The middle part consists of light- to dark-gray limestone beds separated by shale partings; much of the limestone is cherty. The lower part is thin-bedded impure blue limestone containing crinoid stems and other fossil fragments. A persistent bed near the base contains needles of black tourmaline.	**Not an important source of water in this area.**
Devonian	Upper	Three Forks shale	270-282	Composed essentially of black shale and beds of limestone. A 15-foot bed of black carbonaceous shale at the top of the formation rests on light-colored calcareous shale that grades downward into earthy shale with interbedded quartzite.	**Generally either not water bearing or productive of only meager supplies.**
		Jefferson limestone	243	Dark-colored limestone with some light-colored beds. The dark beds have a granular structure, are commonly mottled by light-colored patches of metamorphosed corals, and produce a fetid odor when struck with a hammer.	**Yields water to small springs from joints and solution passages.**

(Lorenz, 1951)

.--Sedimentary rocks of the Helena Valley and their water-bearing properties--Continued

Age		Formation	Thickness (feet)	Lithologic character	Water supply
Cambrian	Upper	Dry Creek shale	175-490	Light-colored thin-bedded limestone with crinkled bands of jasper; in places the rock is composed of limestone pebbles held in a glauconitic matrix. Basal 40 feet consist of brownish-yellow, red, and pink shale and calcareous sandstone.	Yields very little water.
		Pilgrim limestone	317	Massive blue to dark-gray limestone. The upper bed is a light-gray limestone. The lowest bed is a dark crystalline rock mottled with yellow and dark-gray spots.	Yields water for small springs from joints, bedding planes, and solution channels.
	Middle	Park shale	150	Earthy and micaceous dark-gray to green or purple shales, not well indurated.	Not water bearing.
		Meagher limestone	400	Light-gray to blue limestone and shale. Thin-bedded fossiliferous limestone at top grades downward into massive limestone that becomes shaly near the base.	Not water bearing.
		Wolsey shale	420	Micaceous and calcareous gray to green shale with small concretions of limestone.	Not water bearing.
		Flathead quartzite	300	Hard fine-grained massive quartzite to gray and yellow sandstone. In upper part are thin beds of gray, brown, and green micaceous shale. The lowest stratum is pebbly in places, grading into a conglomerate at the base. The pebbles in the basal beds consist chiefly of material derived from the underlying rocks.	Yields water to small springs from numerous cracks and fractures.
Pre-Cambrian	Belt series	Marsh shale	75-300	Red and yellowish-green shale and thin-bedded sandstone.	May yield small supplies locally.
		Helena limestone	2,400	Impure blue to gray noncrystalline limestone occurring in beds 1 to 6 feet thick separated by thin bands of shale. The limestone is blue on fresh fracture but has a characteristic buff velvety-appearing surface on weathering.	Yields small supplies to shallow wells and springs.
		Empire shale	600	Shale and greenish-gray slate with characteristic purple spots.	Yields small supplies to springs.
		Spokane shale	1,500	Massive and thin-bedded siliceous shale, commonly deep-red.	Yields small supplies to numerous springs.
		Greyson shale	3,000	Shale, dark-gray, weathering to rusty brown. Dark-gray shale with interbedded quartzitic layers near middle of formation is underlain by a considerable thickness of fissile light-gray to pale-buff shale.	Not water bearing.

APPENDIX A-3

ROCKS OF LEWIS AND CLARK COUNTY

Formation	Geologic Symbol	Description	Depositional Environment	Thickness (feet)	Planning Symbol (see page 10)
Greyson Shale	pꞒg	dark gray-dark brown argillaceous and sandy rock		3,000	S
Helena Limestone	pꞒh	gray laminated argillaceous and dolomitic limestone		2,400	L
Missoula Group	pꞒm	red, purple argillite, sandy or quartzitic; limestone; Marsh Shale in the Helena region		18,000	SL
Newland Limestone	pꞒn	dark gray argillaceous, dolomitic linestone		2,000	L
Spokane Shale	pꞒs	red, purple shale		9,150+	S
Undifferentiated Cambrian	Ꞓu				
Three Forks Formation	Du	carbonaceous and calcareous shale with sandstone and limestone; Jefferson limestone	normal to restricted shallow marine	1-240	SL
Undifferentiated Mississippian	Mu				
Phosphoria Formation	Pu	gray and tan dolomite; gray-blue phosphatic and dolomitic shale; chert, sandstone, limestone, quartzite, shale	shelf and offshore marine	0-800	SL
Morrison Formation	Ju	calcareous shale and sandstone	non-marine fluvial, paludal, lacustrine	0-300	S

Formation	Geologic Symbol	Description	Depositional Environment	Thickness (feet)	Planning Symbol (see page 10)
Colorado Shale	Kc	dark gray shale and siltstone	stable marine	1,500-2,200	S
	Kdg	diorite and gabbro			
Eagle Sandstone	Keu	sandstone with lignite beds	neritic-lagoonal-brackish swampy	50- 300	S
Kootenai Formation	Kk	conglomerate, sandstone, shale and mudstone	non-marine	300- 600	S
Montana Group	Km	dark brown-gray sandstone and shale	shallow marine (shale); brackish to fresh water (sandstone)	1,800-2,700	S
St. Mary River Formation	Ksm	green-gray clay with local nodular sandstone			
Volcanic Rocks	Kv	flows			Iv
Tertiary Coarse-Grained Intrusive Rocks	Tg	alkalic syenite, leucite - rich rock, some quartzdiorite			I
Boulder Batholith & Related Stocks	Tkb	quartz monzonite mainly			I
Tertiary Sedimentary Rocks, Undifferentiated	Ts	poorly consolidated stream deposits			S
Tertiary Volcanic Rocks	Tv	flows and pyroclastics - mostly latite, andesite; some rhyolite and basalt			Iv

Formation	Geologic Symbol	Description	Depositional Environment	Thickness (feet)	Planning Symbol (see page 10)
Alluvium	Qal	mainly valley fill of silt, sand, and gravel; some glacial drift of Pleistocene age			Q
Glacial Drift	Qg	moraine and outwash of mountain glacier			Q
Terrace Deposits	QTt	gravel, sand and silt			Q

APPENDIX A-4

THER		Vehicle & equipment movement	Water sprinklers	Disease & insect control	Domestic animals influence.	Exotic introduction	Fertilizer application	Material brought in for lawn	Fences erected	Well digging	Septic tanks & drain fields	Utilities	Rigid structures	Tree thinning	Blasting & drilling	Earth cutting & filling	Excavation	Site stripping	Vegetation removal	gravelling & pavement	ditching & drainage control	Bridge & culvert install.	Road construction & mainten.	- flag up, warning includes onsite, offsite, direct & indirect relationship ADVERSE ENVIRONMENTAL IMPACTS RESIDENTIAL
																								- HYDROLOGY
																								Aquifers
																								Recharge zones
																								Ground H_2O Sources
																								Depth to ground water
																								Expanse of surface wate
																								High & low water mark
																								Water quality
																								Watersheds scenic valu

▼ - flag up, warning includes onsite, offsite, direct & indirect relationship

ADVERSE ENVIRONMENTAL IMPACTS	RESIDENTIAL																						THER	
	Road construction & mainten.	Bridge & culvert install.	Ditching & drainage control	Gravelling & pavement	Vegetation removal	Site stripping	Excavation	Earth cutting & filling	Blasting & drilling	Tree thinning	Rigid structures	Utilities	Septic tanks & drain fields	Well digging	Fences erected	Material brought in for lawn	Fertilizer application	Exotic introduction	Domestic animals influence	Disease & insect control	Water sprinklers	Vehicle & equipment movement		
SOILS																								
Soil depth																								
Water holding capacity																								
Surface permeability																								
Sub-surface permeability																								
Shrink-swell																								
Erosion potential																								
Limitations on water availability																								
Limitations on sewage availability																								
Bearing strength																								
Corrosion potential																								
Soil chemistry (pH, alkalinity, salinity)																								
A.A.S.H.O. ratings																								
Frost Action																								

- flag up, warning includes onsite, offsite, direct & indirect relationship

ADVERSE ENVIRONMENTAL IMPACTS

RESIDENTIAL

GEOLOGY	Road construction & mainten.	Bridge & culvert install.	ditching & drainage control	gravelling & pavement	Vegetation removal	Site stripping	Excavation	Earth cutting & filling	Blasting & drilling	Tree thinning	Rigid structures	Utilities	Septic tanks & drain fields	Well digging	Fences erected	Material brought in for lawn	Fertilizer application	Exotic introduction	Domestic animals influence.	Disease & insect control	Water sprinklers	Vehicle & equipment movement	OTHER	
Bedrock geology																								
Surficial geology																								
Features of unique scientific & educ. value																								
Landslides																								
Faults																								
Seismic response																								
Slope stability																								
Potential settlement																								
Degree of weathering																								
Strength of geological foundation																								
Stream cutting																								
Ease of Excavation																								
Fluvial movements																								
General topography																								
Scenic Land Features																								
Scenic Water features																								
Landforms																								
Slope--contour intervals																								
Slope aspect																								

⚑ - flag up, warning includes onsite, offsite, direct & indirect relationship

ADVERSE ENVIRONMENTAL IMPACT

ACTIVE RECREATION

OTHER				Trampling, man	Removal of danger trees	Insect control	Sanitary spraying	Landscaping	Trailer hookups	Parking places	Campground maintenance	Garbage accumulation & removal	Trail building	observation points	signs	fireplaces	water system	picnic tables	boatdocks	Washhouse and privy	Installation of	Developing access	GEOLOGY
																							Bedrock geology
																							Surficial geology
																							Features of unique scientific & educ. value
																							Landslides
																							Faults
																							Seismic response
																							Slope stability
																							Potential settlement
																							Degree of weathering
																							Strength of geological foundation
																							Stream cutting
																							Ease of Excavation
																							Fluvial movements
																							General topography
																							Scenic Land Features
																							Scenic Water features
																							Landforms
																							Slope--contour intervals
																							Slope aspect
																							Surface drainage

APPENDIX B-1

Some Geologic Hints for the Planner:

Water

Granite-if decomposed, good for filtering.
-if bouldery, not good for filtering.

Faults and Fractures-affect water storage and transmissivity of rocks. Some fault zones are more permeable than the rocks they pass through and provide passages for groundwater movement while others are less permeable and act as barriers.

Landslides

Removing support from (ex., excavation) and adding load to (ex., construction, adding fill) a slope are chief ways in which man causes landslides.

Removing vegetation increases runoff and therefore erosion which oversteepens slopes and may lead to sliding.

Loose or poorly consolidated material is especially susceptible to sliding and may fail if saturated with water or is otherwise overloaded without adequate advance preventive measures.

Rockfalls

Areas particularly subject to them are on or just below cliffs.

Potentially Unstable Slopes may occur where

Bedding in sedimentary rocks is nearly parallel to the slope; extensive excavation could undercut the slope and promote sliding of rock downward along the bedding planes. Slopes in claystone or shale have more potential for failure than slopes in other rock types.

Steep slopes are overlain by relatively thick unconsolidated debris that might slide if undercut.

Steep slopes are underlain by fractured granitic rock; saturation by rainfall, snowmelt or water diversion, or undercutting by streams in flood may cause sliding.

Earthquake Hazard

Structures built on loosely or partly consolidated surficial materials instead of bedrock are more likely to be damaged by vibration during a major earthquake.

Swelling Pressure Categories

Very critical	above 4,700 pounds per square foot
Critical	3,200 to 4,700 psf
Marginal	2,700 to 3,200 psf
Noncritical	0 to 2,700 psf

Sanitary Landfill Sites should

- Be in material of low permeability (few fractures).
- Not intersect aquifers.
- Be at least 20 to 30 feet above the highest seasonal level of the water table to minimize the contamination of groundwater from leachate.
- Be far enough from streams to protect surface water from contamination and located so that it will not be inundated by floods.
- Have suitable cover material (relatively impermeable) near the site.
- Not be located over a fault.

Ease of Excavation

- Common excavation includes easily excavated unconsolidated sand and gravel to more difficult to move boulder fields.
- Rock excavation includes friable sandstones easily drilled and broken by blasting to hard durable limestones that are difficult to drill and require much blasting.

APPENDIX B-2

Age of Geologic Formations

Era	Period	Epoch	Age Range*†
Cenozoic	Quartenary	Recent	0–11,000 years
		Pleistocene	11,000–1 million
	Tertiary	Pliocene	1–13 million years
		Miocene	13–25
		Oligocene	25–36
		Eocene	36–58
		Paleocene	58–63
Mesozoic	Cretaceous	Upper	63–90
		Lower	90–135
	Jurassic		135–181
	Triassic		181–230
Paleozoic	Permian		230–280
	Pennsylvanian	Carboniferous	280–310
	Mississippian		310–345
	Devonian		345–405
	Silurian		405–425
	Ordovician		425–500
	Cambrian		500–600
PreCambrian	Proterozoic		600+
	Archeozoic		?

* Kulp, J. L., "Geologic Time Scale," *Science*, 133, 1961, p. 1105–1114.

† There is considerable controversy in ages in the Paleozoic Era and in the beginning of the Recent and Pleistocene epochs. The Pleistocene may have begun as long ago as 2.5 million years and ended as late as 5000 years ago according to some authorities.

(Sowers and Sowers, 1970)

APPENDIX B-3

THE PHYSICAL PROPERTIES OF SOME COMMON ROCK TYPES*

* Tables A, B, D, E, G, H, I, J from Kessler and Sligh, *U. S. Bureau of Standards Research Paper R P 1320,* 1940. Tables C, F from *The International Critical Tables,* 1927.

TABLE A. WEIGHT PER CUBIC FOOT

Material	*Weight (lb/cu ft)*
Granite	162–172
Marble	165–179
Limestone	117–175
Slate	168–180
Quartzite	165–170
Sandstone	119–168

TABLE B. COMPRESSIVE STRENGTH

Material	*Compressive Strength (lb/in^2)*
Granite	5000–60,000
Marble	8000–27,000
Limestone	2600–28,000
Sandstone	5000–20,000
Quartzite	16,000–45,000
Brick	1000–20,000

TABLE C. TENSILE STRENGTH

Material	*Tensile Strength (lb/in^2)*
Granite	427 to 711
Limestone	427 to 853
Marble	427 to 1280
Sandstone	142 to 427

TABLE D. SHEARING STRENGTH

Material	*Shearing Strength (lb/in^2)*
Granite	3700–4800
Slate	2000–3600
Marble	1300–6500
Limestone	800–3600
Sandstone	300–3000

TABLE E. FLEXURAL STRENGTH

Material	*Modulus of Rupture (lb/in^2)*
Granite	1380– 5550
Marble	600– 4000
Limestone	500– 2000
Slate	6000–15,000
Sandstone	700– 2300

(Trefethen, 1959)

Table F. Elasticity

Material	*Modulus of Elasticity (lb/in²)*
Granite	4,545,000 to 8,700,000
Marble	7,250,000 to 10,150,000
Slate	8,700,000 to 13,050,000
Limestone	4,350,000 to 8,700,000
Sandstone	2,320,000 to 1,885,000

Table G. Toughness

(For this test the specimen was mounted securely on a heavy cast-iron base. A steel plunger with the lower end rounded rests on the specimen, and a 2-kg weight is dropped on the plunger by a motor driven sprocket chain. The height of the first drop is 1 cm, and each succeeding drop is increased by 1 cm.)

Material	*Toughness*	
	Range	*Average*
Granite	7 to 28	13
Diorite	6 to 38	23
Basalt	5 to 40	20
Diabase	6 to 50	19
Quartzite	5 to 30	15
Sandstone	2 to 35	10
Limestone	5 to 20	7
Marble	2 to 23	6
Slate	10 to 25	—

Table H. Abrasive Hardness

Material	*H_a Values*
Granite	37 to 98
Marble	8 to 42
Limestone	1 to 24
Sandstone	2 to 26
Slate	6 to 12

Table I. Absorption

Material	*Absorption by Weight (%)*
Granite	0.07 to 0.30
Marble	0.06 to 0.45
Slate	0.01 to 0.60
Quartzite	0.10 to 2.00
Sandstone	2.00 to 12.00
Brick	0.20 to 30.00

Table J. Porosity

Material	*Porosity (%)*
Granite	0.4 to 3.84
Marble	0.4 to 2.1
Slate	0.1 to 1.7
Quartzite	1.5 to 2.9
Sandstone	1.9 to 27.3
Limestone	1.1 to 31.0

Compressive Strengths of Rocks (General Values)*

Compressive strength, psi	*Type of rock*
Over 40,000	Some basalts, diabase, some quartzites
25,000–40,000	Fine-grained granites, diorite, basalt, compact, well-cemented sandstones and limestones, quartzite
10,000–25,000	Average sandstones and limestones, medium- and coarse-grained granites, gneiss
5,000–10,000	Porous sandstones and limestones, shales
Under 5,000	Tuff, chalk, very porous sandstone, siltstone

* From A. von Moos and F. de Quervain, "Technische Gesteinkunde," Birkhaeuser Verlag, Basel, Switzerland, 1948.

(Krynine and Judd, 1957)

CAUSES OF INSTABILITY

Causes of Increased Stresses

1. External loads such as buildings, water, or snow.
2. Increase in unit weight by increased water content.
3. Removal of part of mass by excavation.
4. Undermining, caused by tunneling, collapse of underground caverns, or seepage erosion.
5. Shock, caused by earthquake or blasting.
6. Tension cracks.
7. Water pressure in cracks.

Causes of Decreased Strength

1. Swelling of clays by adsorption of water.
2. Pore water pressure (neutral stress).
3. Breakdown of loose or honeycombed soil structure with shock, vibration or seismic activity.
4. Hair cracking from alternate swelling and shrinking or from tension.
5. Strain, and progressive failure in sensitive soils.
6. Thawing of frozen soil or frost lenses.
7. Deterioration of cementing material.
8. Loss of capillary tension on drying.

Failure could result from any one or any combination of these factors. Most are independent, but some may be interdependent. For example, progressive strain in loose saturated sands causes a neutral stress increase that leads to a loss of strength and possibly a breakdown or collapse of soil structure. The possible number of combinations of factors leading to stability is staggering: 15!, or 1,307,674,368,000. The effect of water is vital: water pressure or changes in water are involved in 10 of the 15 factors listed.

In cases of failures that result in property damage or loss of life, the engineer is often called upon to determine *the* cause of the failure. In most cases a number of causes exist simultaneously, and so attempting to decide which one finally produced failure is not only difficult but also incorrect. Often the final factor is nothing more than a trigger that set in motion an earth mass that was already on the verge of failure. Calling the final factor *the cause* is like calling the match that lit the fuse that detonated the dynamite that destroyed the building *the* cause of the disaster.

(Sowers and Sowers, 1970)

APPENDIX B-4

GEOPHYSICAL METHODS*

Method	Principle	Use	Limitations
Refraction Seismic	Shock wave by hammer impact or small explosive near ground surface. Time of travel to geophones at different distances measured. Shock may travel to distant phone faster through deeper hard strata than by shortest path.	Depth to ground water; depth to successively harder strata; possible estimate of rigidity and location of sink holes.	Interpretation questionable with irregular or poorly defined boundaries; will not identify soft strata under more rigid strata.
Electrical Resistivity	Electric current passed between electrodes at varied spacings. Potential drop between intermediate electrodes and current define apparent resistivity. Depth and resistivity of strata determined by resistivity-electrode spacing relations.	Depth to strata of different resistivities and groundwater. Location of masses of dry sands and gravels or hard rock.	Interpretation questionable with irregular or poorly defined boundaries.
Gravity	Measure earth's gravity by sensitive torsion balance.	Locate major structural anamolies: faults, domes, possibly large cavities.	Will not identify structures unless major differences in density involved.
Sonic	Time of travel of sound or super-sonic wave through water and soft silt and reflected upward by stratum changes.	Depth of water and soft silt above hard bottom.	Of little or no use in continuous soil or soil-rock.

* Reflection seismic, magnetic, self potential, and radiation sometimes useful in specialized applications such as well logging and mineral surveys.

(Sowers and Sowers, 1970)

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* indicates that the publication relates to Montana.

THE RESOURCES DEVELOPMENT INTERNSHIP PROGRAM

The preceding report was completed by a WICHE intern during the summer of 1973 This intern's project was part of the Resources Development Internship Program administered by the Western Interstate Commission for Higher Education (WICHE).

The purpose of the internship program is to bring organizations involved in community and economic development, environmental problems and the humanities together with institutions of higher education and their students in the West for the benefit of all.

For these organizations, the intern program provides the problem-solving talents of student manpower while making the resources of universities and colleges more available. For institutions of higher education, the program provides relevant field education for their students while building their capacity for problem-solving.

WICHE is an organization in the West uniquely suited for sponsoring such a program. It is an interstate agency formed by the thirteen western states for the specific purpose of relating the resources of higher education to the needs of western citizens. WICHE has been concerned with a broad range of community needs in the West for some time, insofar as they bear directly on the well-being of western peoples and the future of higher education in the West. WICHE feels that the internship program is one method for meeting its obligations within the thirteen western states. In its efforts to achieve these objectives, WICHE appreciates having received the generous support and assistance of the Economic Development Administration, the Jessie Smith Noyes Foundation, the National Endowment for the Humanities, the National Science Foundation, and of innumerable local leaders and community organizations, including the agency that sponsored this intern project.

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